W

$J = 1$

THE MASS OF THE *W* BOSON

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Till 1995 the production and study of the W boson was the exclusive domain of the $\overline{p}p$ colliders at CERN and FNAL. W production in these hadron colliders is tagged by a high p_T lepton from W decay. Owing to unknown parton–parton effective energy and missing energy in the longitudinal direction, the experiments reconstruct only the transverse mass of the W and derive the W mass from comparing the transverse mass distribution with Monte Carlo predictions as a function of M_W.

Beginning 1996 the energy of LEP increased to above 161 GeV, the threshold for W–pair production. A precise knowledge of the e^+e^- centre of mass energy enables one to reconstruct the W mass even if one of them decays leptonically. At LEP two methods have been used to obtain the W mass. In the first method the measured W–pair production cross sections, $\sigma(e^+e^- \rightarrow W^+W^-)$, have been used to determine the W mass using the predicted dependence of this cross section on M_W (see Fig. 1). At 161 GeV, which is just above the W–pair production threshold, this dependence is a much more sensitive function of the W mass than at the higher energies (172 to 202 GeV) at which LEP has run during 1996–99. In the second method, which is used at the higher energies, the W mass has been determined by directly reconstructing the W from its decay products.

Each LEP experiment has combined their own mass values properly taking into account the common systematic errors. In order to compute the LEP average W mass each experiment

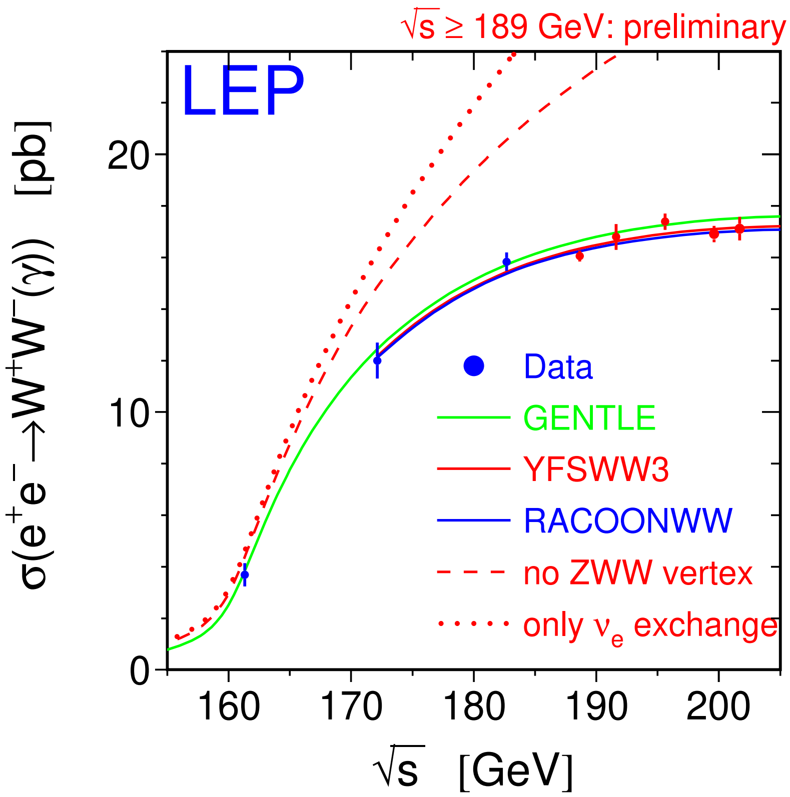

Figure 1: The W–pair cross section as a function of the center–of–mass energy. The data points are the LEP averages. The solid lines are predictions from different models of WW production. For comparison the figure contains also the cross section if the ZWW coupling did not exist (dashed line), or if only the t–channel ν_e exchange diagram existed (dotted line).

has provided its measured W mass for the $qqqq$ and $qq\ell\nu$ channels at each center-of-mass energy along with a detailed break-up of errors (statistical and uncorrelated, partially correlated and fully correlated systematics [1]). These have been properly combined to obtain a *preliminary* [2] LEP W mass

= 80.401±0.048 GeV. Errors due uncertainties in LEP energy (17 MeV) and possible effect of color reconnection (CR) and Bose–Einstein (BE) correlations between quarks from different W's (18 MeV) are included. The mass difference between $qqqq$ and $qq\ell\nu$ final states (due to possible CR and BE effects) is 35±55 MeV.

The two Tevatron experiments have also carried out the exercise of identifying common systematic errors and averaging with CERN UA2 data obtain an average W mass = 80.448±0.062 GeV.

Combining all the published and unpublished p–$\overline{p}$ Collider and LEP results (as of mid-March 2000) yields an average W–boson mass of 80.419±0.038 GeV assuming no common systematics between LEP and hadron collider measurements.

The Standard Model prediction from the electroweak fit, excluding the direct W mass measurements from LEP and Tevatron, gives a W–boson mass of 80.382 ± 0.026 GeV.

OUR EVALUATION in the listing below is obtained by combining only published LEP and p–$\overline{p}$ Collider results using the same procedure as above.

References

1. The LEP Collaborations: ALEPH, DELPHI, L3, OPAL, the LEP Electroweak Working Group, and the SLD Heavy Flavour and Electroweak Groups, CERN-EP-2000-016 (January 21, 2000).
2. A. Straessner and C. Sbarra, talks presented at the XXXV Rencontres de Moriond, "Electroweak Interactions and Unified Theories," (Les Arcs, France, 11–18 March 2000).

W MASS

OUR FIT uses the W and Z mass, mass difference, and mass ratio measurements.

To obtain OUR EVALUATION the correlation between systematics is properly taken into account.

VALUE (GeV)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
80.419 ± 0.056 OUR EVALUATION					
80.43 ± 0.05 OUR FIT					
80.482 ± 0.091	45394	[1] ABBOTT	00	D0	$E^{p\overline{p}}_{\rm cm}$ = 1.8 TeV
80.38 ± 0.12 ± 0.05	701	[2] ABBIENDI	99C	OPAL	$E^{ee}_{\rm cm}$ = 161+172+ 183 GeV
80.270 ± 0.137 ± 0.048	809	[3] ABREU	99T	DLPH	$E^{ee}_{\rm cm}$ = 161+172+ 183 GeV
80.61 ± 0.15	801	[4] ACCIARRI	99	L3	$E^{ee}_{\rm cm}$ = 161+172+ 183 GeV
80.423 ± 0.112 ± 0.054	812	[5] BARATE	99	ALEP	$E^{ee}_{\rm cm}$ = 161+172+ 183 GeV
80.41 ± 0.18	8986	[6] ABE	95P	CDF	$E^{p\overline{p}}_{\rm cm}$ = 1.8 TeV
79.91 ± 0.39	1722	[7] ABE	90G	CDF	$E^{p\overline{p}}_{\rm cm}$ = 1.8 TeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
80.49 ± 0.43 ± 0.095	871	[8] ABREU	99K	DLPH	Repl. by ABREU 99T
80.44 ± 0.10 ± 0.07	28323	[9] ABBOTT	98O	D0	Repl. by ABBOTT 00
80.22 ± 0.41 ± 0.07	72	[10] ABREU	98B	DLPH	Repl. by ABREU 99T
80.32 ± 0.30 ± 0.094	96	[11] ACKERSTAFF	98D	OPAL	Repl. by ABBIENDI 99C
80.5 $^{+1.4}_{-2.2}$ $^{+0.5}_{-0.6}$	104	[12] ACKERSTAFF	98D	OPAL	Repl. by ABBIENDI 99C
80.80 ± 0.32 ± 0.114	95	[13] BARATE	98B	ALEP	Repl. by BARATE 99
80.80 $^{+0.48}_{-0.42}$ ± 0.03	20	[14] ACCIARRI	97	L3	Repl. by ACCIARRI 99
80.5 $^{+1.4}_{-2.4}$ ± 0.3	94	[15] ACCIARRI	97M	L3	Repl. by ACCIARRI 99
80.71 $^{+0.34}_{-0.35}$ ± 0.09	101	[16] ACCIARRI	97S	L3	Repl. by ACCIARRI 99
80.14 ± 0.34 ± 0.095	32	[17] BARATE	97	ALEP	Repl. by BARATE 99
81.17 $^{+1.15}_{-1.62}$	106	[18] BARATE	97S	ALEP	Repl. by BARATE 99
80.35 ± 0.14 ± 0.23	5982	[19] ABACHI	96E	D0	Repl. by ABBOTT 00
80.40 $^{+0.44}_{-0.41}$ $^{+0.09}_{-0.10}$	23	[20] ACKERSTAFF	96B	OPAL	Repl. by ABBIENDI 99C
84 $^{+10}_{-7}$	13	[21] AID	96D	H1	$e^{\pm} p \rightarrow \nu_e(\overline{\nu}_e) + X$ $\sqrt{s} \approx 300$ GeV
80.84 ± 0.22 ± 0.83	2065	[22] ALITTI	92B	UA2	See W/Z ratio below
80.79 ± 0.31 ± 0.84		[23] ALITTI	90B	UA2	$E^{p\overline{p}}_{\rm cm}$ = 546,630 GeV
80.0 ± 3.3 ± 2.4	22	[24] ABE	89I	CDF	$E^{p\overline{p}}_{\rm cm}$ = 1.8 TeV
82.7 ± 1.0 ± 2.7	149	[25] ALBAJAR	89	UA1	$E^{p\overline{p}}_{\rm cm}$ = 546,630 GeV
81.8 $^{+6.0}_{-5.3}$ ± 2.6	46	[26] ALBAJAR	89	UA1	$E^{p\overline{p}}_{\rm cm}$ = 546,630 GeV
89 ± 3 ± 6	32	[27] ALBAJAR	89	UA1	$E^{p\overline{p}}_{\rm cm}$ = 546,630 GeV
81. ± 5.	6	ARNISON	83	UA1	$E^{ee}_{\rm cm}$ = 546 GeV
80. $^{+10.}_{-6.}$	4	BANNER	83B	UA2	Repl. by ALITTI 90B

[1] ABBOTT 00 use $W \rightarrow e\nu_e$ events to measure the W mass with a fit to the transverse mass distribution. The result quoted here corresponds to electrons detected both in the forward and in the central calorimeters for the data recorded in 1992–1995. For the large rapidity electrons recorded in 1994–1995, the analysis combines results obtained from m_T, $p_T(e)$, and $p_T(\nu)$.

[2] ABBIENDI 99C obtain this value properly combining results from a direct W mass reconstruction at 172 and 183 GeV with that from the measurement of the total W-pair production cross section at 161 GeV. The systematic error includes an uncertainty of ± 0.02 GeV due to the possible color-reconnection and Bose-Einstein effects in the purely hadronic final states and an uncertainty of ± 0.02 GeV due to the beam energy.

[3] ABREU 99T obtain this value properly combining results obtained from a direct W mass reconstruction at 172 and 183 GeV with those from measurement of W-pair production cross sections at 161, 172, and 183 GeV. The systematic error includes ± 0.021 GeV due to the beam energy uncertainty and ± 0.030 GeV due to possible color reconnection and Bose-Einstein effects in the purely hadronic final state.

[4] ACCIARRI 99 obtain this value properly combining results obtained from a direct W mass reconstruction at 172 and 183 GeV with those from the measurements of the total W-pair production cross sections at 161 and 172 GeV. The value of the mass obtained from the direct reconstruction at 172 and 183 GeV is $M(W)= 80.58 \pm 0.14 \pm 0.08$ GeV.

[5] BARATE 99 obtain this value properly combining results from a direct W mass reconstruction at 172 and 183 GeV with those from the measurements of the total W-pair production cross sections at 161 and 172 GeV. The systematic error includes ± 0.023 GeV due to LEP energy uncertainty and ± 0.021 GeV due to theory uncertainty on account of possible color reconnection and Bose-Einstein correlations.

[6] ABE 95P use 3268 $W \rightarrow \mu\nu_\mu$ events to find $M = 80.310 \pm 0.205 \pm 0.130$ GeV and 5718 $W \rightarrow e\nu_e$ events to find $M = 80.490 \pm 0.145 \pm 0.175$ GeV. The result given here combines these while accounting for correlated uncertainties.

[7] ABE 90G result from $W \rightarrow e\nu$ is $79.91 \pm 0.35 \pm 0.24 \pm 0.19$(scale) GeV and from $W \rightarrow \mu\nu$ is $79.90 \pm 0.53 \pm 0.32 \pm 0.08$(scale) GeV.

[8] ABREU 99K derive this value using the Standard Model dependence on M_W of the W-W production cross sections measured at 161, 172, and 183 GeV. The systematics include an error of ± 0.03 GeV arising from the beam energy uncertainty.

[9] ABBOTT 98O fit the transverse mass distribution of 28323 $W \rightarrow e\nu_e$ events. The systematic error includes a detector related uncertainty of ± 60 MeV and a model uncertainty of ± 30 MeV. Combining with ABACHI 96E DØ obtain a W mass value of 80.43 ± 0.11 GeV.

[10] ABREU 98B obtain this value from a fit to the reconstructed W mass distribution. The W width was taken as its Standard Model value at the fitted W mass. The systematic error includes ± 0.03 GeV due to the beam energy uncertainty and ± 0.05 GeV due to the possible color reconnection and Bose-Einstein effects in the purely hadronic final state.

[11] ACKERSTAFF 98D obtain this value from a fit to the reconstructed W mass distribution. The W width was taken as its Standard Model value at the fitted W mass. When both W mass and width are varied they obtain $M(W) = 80.30 \pm 0.27 \pm 0.095$ GeV. The systematic error includes ± 0.03 GeV due to the beam energy uncertainty and ± 0.05 GeV due to the possible color reconnection and Bose-Einstein effects in the purely hadronic final state. Combining both values of ACKERSTAFF 98D with ACKERSTAFF 96B authors find: $M(W) = 80.35 \pm 0.24 \pm 0.07 \pm 0.03$ (LEP) GeV.

[12] ACKERSTAFF 98D derive this value from their measured $W W$ production cross section $\sigma_{WW} = 12.3 \pm 1.3 \pm 0.4$ pb using the Standard Model dependence of σ_{WW} on M_W at the given c.m. energy.

[13] BARATE 98B obtain this value from a fit to the reconstructed W mass distribution. The W width was taken as its Standard Model value at the fitted W mass. The systematic error includes ± 0.03 GeV due to the beam energy uncertainty and ± 0.032 GeV due to the possible color reconnection and Bose-Einstein effects in the purely hadronic final state. Combining with the M_W values from cross section measurements at 161 and 172 GeV (BARATE 97 and BARATE 97S) authors find: $M(W) = 80.51 \pm 0.23 \pm 0.08$ GeV.

[14] ACCIARRI 97 derive this value from their measured W-W production cross section $\sigma_{WW} = 2.89^{+0.81}_{-0.70} \pm 0.14$ pb using the Standard Model dependence of σ_{WW} on M_W at the given c.m. energy. Statistical and systematic errors are added in quadrature and the last error of ± 0.03 GeV arises from the beam energy uncertainty. The same result is given by a fit of the production cross sections to the data.

[15] ACCIARRI 97M derive this value from their measured WW production cross section $\sigma_{WW} = 12.27^{+1.41}_{-1.32} \pm 0.23$ pb using the Standard Model dependence of σ_{WW} on M_W at the given c.m. energy. Combining with ACCIARRI 97 authors find $M(W) = 80.78^{+0.45}_{-0.41} \pm 0.03$ GeV where the last error is due to beam energy uncertainty.

[16] ACCIARRI 97S obtain this value from a fit to the reconstructed W mass distribution. The W width was taken as its Standard Model value at the fitted W mass. When both W mass and width are varied they obtain $M(W) = 80.72^{+0.31}_{-0.33} \pm 0.09$ GeV. The systematic error includes ± 0.03 GeV due to the beam energy uncertainty and ± 0.05 GeV due to the possible color reconnection and Bose-Einstein effects in the purely hadronic final state. Combining with ACCIARRI 97 and ACCIARRI 97M authors find: $M(W) = 80.75^{+0.26}_{-0.27} \pm 0.03$ (LEP) GeV.

[17] BARATE 97 derive this value from their measured W-W production cross section $\sigma_{WW} = 4.23 \pm 0.73 \pm 0.19$ pb using the Standard Model dependence of σ_{WW} on M_W at the given c.m. energy. The systematics include an error of ± 0.03 GeV arising from the beam energy uncertainty.

[18] BARATE 97S derive this value from their measured WW production cross section $\sigma_{WW} = 11.71 \pm 1.23 \pm 0.28$ pb using the Standard Model dependence of σ_{WW} on M_W at the given c.m. energy. The errors quoted on the mass are statistical only. Combining with BARATE 97 authors find: $M(W) = 80.20 \pm 0.33 \pm 0.09 \pm 0.03$ (LEP) GeV.

[19] ABACHI 96E fit the transverse mass distribution of 5982 $W \rightarrow e\nu_e$ decays. An error of ± 160 MeV due to the uncertainty in the absolute energy scale of the EM calorimeter is included in the total systematics.

[20] ACKERSTAFF 96B derive this value from an analysis of the predicted M_W dependence of their accepted four-fermion cross section, explicitly taking into account interference effects. The systematics include an error of ± 0.03 GeV arising from the beam energy uncertainty.

[21] AID 96D derive this value as a propagator mass using the Q^2 shape and magnitude of the $e^{\pm}$ charged-current cross sections. $Q^2 > 5000\ \text{GeV}^2$ events with p_T of the outgoing lepton > 25 GeV/c are used.

[22] ALITTI 92B result has two contributions to the systematic error (± 0.83); one (± 0.81) cancels in m_W/m_Z and one (± 0.17) is noncancelling. These were added in quadrature. We choose the ALITTI 92B value without using the LEP m_Z value, because we perform our own combined fit.

[23] There are two contributions to the systematic error (± 0.84): one (± 0.81) which cancels in m_W/m_Z and one (± 0.21) which is non-cancelling. These were added in quadrature.

[24] ABE 89I systematic error dominated by the uncertainty in the absolute energy scale.

[25] ALBAJAR 89 result is from a total sample of 299 $W \rightarrow e\nu$ events.

[26] ALBAJAR 89 result is from a total sample of 67 $W \rightarrow \mu\nu$ events.

[27] ALBAJAR 89 result is from $W \rightarrow \tau\nu$ events.

W/Z MASS RATIO

The fit uses the W and Z mass, mass difference, and mass ratio measurements.

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
0.8820 ±0.0005 OUR FIT				
0.8821 ±0.0011 ±0.0008	28323	[28] ABBOTT 98N	D0	$E^{p\overline{p}}_{\text{cm}} = 1.8$ TeV

0.88114±0.00154±0.00252	5982	[29] ABBOTT	98P	D0	$E^{p\overline{p}}_{\rm cm}$= 1.8 TeV
0.8813 ±0.0036 ±0.0019	156	[30] ALITTI	92B	UA2	$E^{p\overline{p}}_{\rm cm}$= 630 GeV

[28] ABBOTT 98N obtain this from a study of 28323 $W \rightarrow e\nu_e$ and 3294 $Z \rightarrow e^+e^-$ decays. Of this latter sample, 2179 events are used to calibrate the electron energy scale.

[29] ABBOTT 98P obtain this from a study of 5982 $W \rightarrow e\nu_e$ events. The systematic error includes an uncertainty of ±0.00175 due to the electron energy scale.

[30] Scale error cancels in this ratio.

$m_Z - m_W$

The fit uses the W and Z mass, mass difference, and mass ratio measurements.

VALUE (GeV)	*DOCUMENT ID*		*TECN*	*COMMENT*
10.76±0.05 OUR FIT				
10.4 ±1.4 ±0.8	ALBAJAR	89	UA1	$E^{p\overline{p}}_{\rm cm}$= 546,630 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •				
11.3 ±1.3 ±0.9	ANSARI	87	UA2	$E^{p\overline{p}}_{\rm cm}$= 546,630 GeV

$m_{W^+} - m_{W^-}$

Test of *CPT* invariance.

VALUE (GeV)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
−0.19±0.58	1722	ABE	90G	CDF	$E^{p\overline{p}}_{\rm cm}$= 1.8 TeV

W WIDTH

The CDF and DØ widths labelled "extracted value" are obtained by measuring $R = [\sigma(W)/\sigma(Z)]\ [\Gamma(W \rightarrow \ell\nu_\ell)]/(\mathrm{B}(Z \rightarrow \ell\ell)\Gamma(W))$ where the bracketed quantities can be calculated with plausible reliability. $\Gamma(W)$ is then extracted by using a value of $\mathrm{B}(Z \rightarrow \ell\ell)$ measured at LEP. The UA1 and UA2 widths used $R = [\sigma(W)/\sigma(Z)]\ [\Gamma(W \rightarrow \ell\nu_\ell)/\Gamma(Z \rightarrow \ell\ell)]\ \Gamma(Z)/\Gamma(W)$ and the measured value of $\Gamma(Z)$. The Standard Model prediction is 2.067 ± 0.021 (ROSNER 94).

VALUE (GeV)	*CL%*	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
2.12 ±0.05 OUR AVERAGE						
2.152±0.066		79176	[31] ABBOTT	00B	D0	Extracted value
1.84 ±0.32 ±0.20		674	[32] ABBIENDI	99C	OPAL	$E^{ee}_{\rm cm}$= 172+183 GeV
2.48 ±0.40 ±0.10		737	[33] ABREU	99T	DLPH	$E^{ee}_{\rm cm}$= 183 GeV
1.97 ±0.34 ±0.17		687	[34] ACCIARRI	99	L3	$E^{ee}_{\rm cm}$= 172+183 GeV
2.11 ±0.28 ±0.16		58	[35] ABE	95C	CDF	Direct meas.
2.064±0.060±0.059			[36] ABE	95W	CDF	Extracted value
2.10 $^{+0.14}_{-0.13}$ ±0.09		3559	[37] ALITTI	92	UA2	Extracted value
2.18 $^{+0.26}_{-0.24}$ ±0.04			[38] ALBAJAR	91	UA1	Extracted value

• • • We do not use the following data for averages, fits, limits, etc. • • •

2.044 ± 0.097		11858	[39] ABBOTT	99H	D0	Repl. by ABBOTT 00B
$2.126^{+0.052}_{-0.048} \pm 0.035$			[40] BARATE	99I	ALEP	$E^{ee}_{\rm cm}$= 161+172+183 GeV
$1.30\ ^{+0.70}_{-0.55}\ \pm 0.18$		92	[41] ACKERSTAFF	98D	OPAL	Repl. by ABBIENDI 99C
$1.74\ ^{+0.88}_{-0.78}\ \pm 0.25$		101	[42] ACCIARRI	97S	L3	Repl. by ACCIARRI 99
$2.30\ \pm 0.19\ \pm 0.06$			[43] ALITTI	90C	UA2	Extracted value
$2.8\ ^{+1.4}_{-1.5}\ \pm 1.3$		149	[44] ALBAJAR	89	UA1	$E^{p\overline{p}}_{\rm cm}$= 546,630 GeV
<7	90	119	APPEL	86	UA2	$E^{p\overline{p}}_{\rm cm}$= 546,630 GeV
<6.5	90	86	[45] ARNISON	86	UA1	$E^{p\overline{p}}_{\rm cm}$= 546,630 GeV

[31] ABBOTT 00B measure $R = 10.43 \pm 0.27$ for the $W \rightarrow e\nu_e$ decay channel. They use the SM theoretical predictions for $\sigma(W)/\sigma(Z)$ and $\Gamma(W \rightarrow e\nu_e)$ and the world average for B($Z \rightarrow ee$). The value quoted here is obtained combining this result (2.169 ± 0.070 GeV) with that of ABBOTT 99H.

[32] ABBIENDI 99C obtain this value from a fit to the reconstructed W mass distribution using data at 172 and 183 GeV. The systematic error includes an uncertainty of ± 0.12 GeV due to the possible color-reconnection and Bose-Einstein effects in the purely hadronic final states and an uncertainty of ± 0.01 GeV due to the beam energy.

[33] ABREU 99T obtain this value using $WW \rightarrow \ell\overline{\nu}_\ell q\overline{q}$ and $WW \rightarrow q\overline{q}q\overline{q}$ events. The systematic error includes an uncertainty of ± 0.080 GeV due to possible color reconnection and Bose-Einstein effects in the purely hadronic final state.

[34] ACCIARRI 99 obtain this value from a fit to the reconstrued W mass distribution using data at 172 and 183 GeV.

[35] ABE 95C use the tail of the transverse mass distribution of $W \rightarrow e\nu_e$ decays.

[36] ABE 95W measured $R = 10.90 \pm 0.32 \pm 0.29$. They use m_W=80.23 ± 0.18 GeV, $\sigma(W)/\sigma(Z) = 3.35 \pm 0.03$, $\Gamma(W \rightarrow e\nu) = 225.9 \pm 0.9$ MeV, $\Gamma(Z \rightarrow e^+e^-) = 83.98 \pm 0.18$ MeV, and $\Gamma(Z) = 2.4969 \pm 0.0038$ GeV.

[37] ALITTI 92 measured $R = 10.4^{+0.7}_{-0.6} \pm 0.3$. The values of $\sigma(Z)$ and $\sigma(W)$ come from $O(\alpha_s^2)$ calculations using $m_W = 80.14 \pm 0.27$ GeV, and $m_Z = 91.175 \pm 0.021$ GeV along with the corresponding value of $\sin^2\theta_W = 0.2274$. They use $\sigma(W)/\sigma(Z) = 3.26 \pm 0.07 \pm 0.05$ and $\Gamma(Z) = 2.487 \pm 0.010$ GeV.

[38] ALBAJAR 91 measured $R = 9.5^{+1.1}_{-1.0}$ (stat. + syst.). $\sigma(W)/\sigma(Z)$ is calculated in QCD at the parton level using $m_W = 80.18 \pm 0.28$ GeV and $m_Z = 91.172 \pm 0.031$ GeV along with $\sin^2\theta_W = 0.2322 \pm 0.0014$. They use $\sigma(W)/\sigma(Z) = 3.23 \pm 0.05$ and $\Gamma(Z) = 2.498 \pm 0.020$ GeV. This measurement is obtained combining both the electron and muon channels.

[39] ABBOTT 99H measure R= 10.90 ± 0.52 combining electron and muon channels. They use $M_W = 80.39 \pm 0.06$ GeV and the SM theoretical predictions for $\sigma(W)/\sigma(Z)$, B($Z \rightarrow \ell\ell$), and $\Gamma(W \rightarrow \ell\nu_\ell)$.

[40] BARATE 99I obtain this result with a fit to the WW measured cross sections at 161, 172, and 183 GeV. The theoretical prediction takes into account the sensitivity to the W total width.

[41] ACKERSTAFF 98D obtain this value from a fit to the reconstructed W mass distribution.

[42] ACCIARRI 97S obtain this value from a fit to the reconstructed W mass distribution.

[43] ALITTI 90C used the same technique as described for ABE 90. They measured $R = 9.38^{+0.82}_{-0.72} \pm 0.25$, obtained $\Gamma(W)/\Gamma(Z) = 0.902 \pm 0.074 \pm 0.024$. Using $\Gamma(Z) = 2.546 \pm 0.032$ GeV, they obtained the $\Gamma(W)$ value quoted above and the limits $\Gamma(W) < 2.56$ (2.64) GeV at the 90% (95%) CL. $E^{p\overline{p}}_{\rm cm} = 546,630$ GeV.

[44] ALBAJAR 89 result is from a total sample of 299 $W \to e\nu$ events.
[45] If systematic error is neglected, result is $2.7^{+1.4}_{-1.5}$ GeV. This is enhanced subsample of 172 total events.

W^+ DECAY MODES

W^- modes are charge conjugates of the modes below.

	Mode		Fraction (Γ_i/Γ)	Confidence level
Γ_1	$\ell^+\nu$	[a]	(10.56 ± 0.14) %	
Γ_2	$e^+\nu$		(10.66 ± 0.20) %	
Γ_3	$\mu^+\nu$		(10.49 ± 0.29) %	
Γ_4	$\tau^+\nu$		(10.4 ± 0.4) %	
Γ_5	hadrons		(68.5 ± 0.6) %	
Γ_6	$\pi^+\gamma$		$< 7 \times 10^{-5}$	95%
Γ_7	$D_s^+\gamma$		$< 1.3 \times 10^{-3}$	95%
Γ_8	cX		(35 ± 4) %	
Γ_9	$c\bar{s}$		(32^{+13}_{-11}) %	
Γ_{10}	invisible	[b]	(1.4 ± 2.8) %	

[a] ℓ indicates each type of lepton (e, μ, and τ), not sum over them.

[b] This represents the width for the decay of the W boson into a charged particle with momentum below detectability, p< 200 MeV.

W PARTIAL WIDTHS

Γ(invisible) Γ_{10}

This represents the width for the decay of the W boson into a charged particle with momentum below detectability, p< 200 MeV.

VALUE (MeV)	*DOCUMENT ID*		*TECN*	*COMMENT*
$\mathbf{30^{+52}_{-48}\pm 33}$	[46] BARATE	99I	ALEP	E^{ee}_{cm}= 161+172+183 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •				
	[47] BARATE	99L	ALEP	E^{ee}_{cm}= 161+172+183 GeV

[46] BARATE 99I measure this quantity using the dependence of the total cross section σ_{WW} upon a change in the total width. The fit is performed to the WW measured cross sections at 161, 172, and 183 GeV. This partial width is < 139 MeV at 95%CL.
[47] BARATE 99L use W-pair production to search for effectively invisible W decays, tagging with the decay of the other W boson to Standard Model particles. The partial width for effectively invisible decay is < 27 MeV at 95%CL.

W BRANCHING RATIOS

Overall fits are performed to determine the branching ratios of the W. For each LEP experiment the correlation matrix of the leptonic branching ratios is used and the common systematic errors among LEP experiments are properly taken into account. A first fit determines three individual leptonic branching ratios, $B(W \rightarrow e\nu_e)$, $B(W \rightarrow \mu\nu_\mu)$, and $B(W \rightarrow \tau\nu_\tau)$. This fit has a $\chi^2 = 10.5$ for 20 degrees of freedom. A second fit assumes lepton universality and determines the leptonic branching ratio $B(W \rightarrow \ell\nu_\ell)$. This fit has a χ^2=11.0 for 22 degrees of freedom. A separate fit is performed only to hadronic branching ratio data taking into account the common systematic errors. This fit has a χ^2=2.3 for 3 degrees of freedom.

$\Gamma(\ell^+\nu)/\Gamma_{\text{total}}$ $\qquad\Gamma_1/\Gamma$

ℓ indicates average over e, μ, and τ modes, not sum over modes.

Data marked "fit" are used for the fit. The other data is highly correlated with data appearing elsewhere in the Listings and are therefore not used in the fit.

VALUE		*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
0.1056±0.0014 OUR FIT						
0.1071±0.0024±0.0014		1237	ABREU	00K	DLPH	$E^{ee}_{\rm cm}$= 161+172+183 +189 GeV
0.107 ±0.004 ±0.002		461	ABBIENDI	99D	OPAL	$E^{ee}_{\rm cm}$= 161+172+183 GeV
0.1102±0.0052	fit	11858	[48] ABBOTT	99H	D0	$E^{p\overline{p}}_{\rm cm}$= 1.8 TeV
0.1036±0.0040±0.0017		532	BARATE	99I	ALEP	$E^{ee}_{\rm cm}$= 161+172+183 GeV
0.100 ±0.004 ±0.001		324	ACCIARRI	98P	L3	$E^{ee}_{\rm cm}$= 161+172+183 GeV
0.104 ±0.008	fit	3642	[49] ABE	92I	CDF	$E^{p\overline{p}}_{\rm cm}$= 1.8 TeV
• • • We do not use the following data for averages, fits, limits, etc. • • •						
0.1085±0.0048±0.0017		170	ABREU	99K	DLPH	Repl. by ABREU 00K
0.101 $^{+0.011}_{-0.010}$ ±0.002		61	ACKERSTAFF	98D	OPAL	Repl. by ABBIENDI 99D
0.119 $^{+0.013}_{-0.012}$ ±0.002		51	ACCIARRI	97M	L3	Repl. by ACCIARRI 98P

[48] ABBOTT 99H measure $R \equiv [\sigma_W\, B(W \rightarrow \ell\nu_\ell)]/[\sigma_Z\, B(Z \rightarrow \ell\ell)] = 10.90 \pm 0.52$ combining electron and muon channels. They use $M_W = 80.39 \pm 0.06$ GeV and the SM theoretical predictions for $\sigma(W)/\sigma(Z)$ and $B(Z \rightarrow \ell\ell)$.

[49] $1216 \pm 38^{+27}_{-31}$ $W \rightarrow \mu\nu$ events from ABE 92I and 2426 $W \rightarrow e\nu$ events of ABE 91C. ABE 92I give the inverse quantity as 9.6 ± 0.7 and we have inverted.

$\Gamma(e^+\nu)/\Gamma_{\text{total}}$ Γ_2/Γ

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
0.1066±0.0020 OUR FIT				
0.1044±0.0015±0.0028	67318	[50] ABBOTT 00B	D0	$E^{p\overline{p}}_{\text{cm}}$= 1.8 TeV
0.1018±0.0054±0.0026	352	ABREU 00K	DLPH	E^{ee}_{cm}= 161+172+183 +189 GeV
0.117 ±0.009 ±0.002	191	ABBIENDI 99D	OPAL	E^{ee}_{cm}= 161+172+ 183 GeV
0.1115±0.0085±0.0024	193	BARATE 99I	ALEP	E^{ee}_{cm}= 161+172+ 183 GeV
0.105 ±0.009 ±0.002	128	ACCIARRI 98P	L3	E^{ee}_{cm}= 161+172+ 183 GeV
0.1094±0.0033±0.0031		[51] ABE 95W	CDF	$E^{p\overline{p}}_{\text{cm}}$= 1.8 TeV
0.10 ±0.014 $^{+0.02}_{-0.03}$	248	[52] ANSARI 87C	UA2	$E^{p\overline{p}}_{\text{cm}}$= 546,630 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.1012±0.0107±0.0028	56	ABREU 99K	DLPH	Repl. by ABREU 00K
0.098 $^{+0.022}_{-0.020}$ ±0.003	21	ACKERSTAFF 98D	OPAL	Repl. by ABBIENDI 99D
0.165 $^{+0.037}_{-0.033}$ ±0.005	23	ACCIARRI 97M	L3	Repl. by ACCIARRI 98P
0.097 ±0.02 ±0.005	21	BARATE 97S	ALEP	Repl. by BARATE 99I
seen	119	APPEL 86	UA2	$E^{p\overline{p}}_{\text{cm}}$= 546,630 GeV
seen	172	ARNISON 86	UA1	$E^{p\overline{p}}_{\text{cm}}$= 546,630 GeV

[50] ABBOTT 00B measure $R \equiv [\sigma_W B(W \to e\nu_e)]/[\sigma_Z B(Z \to ee)] = 10.43 \pm 0.27$ for the $W \to e\nu_e$ decay channel. They use the SM theoretical prediction for $\sigma(W)/\sigma(Z)$ and the world average for $B(Z \to ee)$.

[51] ABE 95W result is from a measurement of $\sigma B(W \to e\nu)/\sigma B(Z \to e^+e^-) = 10.90 \pm 0.32 \pm 0.29$, the theoretical prediction for the cross section ratio, the experimental knowledge of $\Gamma(Z \to e^+e^-) = 83.98 \pm 0.18$ MeV, and $\Gamma(Z) = 2.4969 \pm 0.0038$ GeV.

[52] The first error was obtained by adding the statistical and systematic experimental uncertainties in quadrature. The second error reflects the dependence on theoretical prediction of total W cross section: $\sigma(546\ \text{GeV}) = 4.7^{+1.4}_{-0.7}$ nb and $\sigma(630\ \text{GeV}) = 5.8^{+1.8}_{-1.0}$ nb. See ALTARELLI 85B.

$\Gamma(\mu^+\nu)/\Gamma_{\text{total}}$ Γ_3/Γ

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
0.1049±0.0029 OUR FIT				
0.1092±0.0048±0.0012	461	ABREU 00K	DLPH	E^{ee}_{cm}= 161+172+183 +189 GeV
0.102 ±0.008 ±0.002	169	ABBIENDI 99D	OPAL	E^{ee}_{cm}= 161+172+ 183 GeV
0.1006±0.0078±0.0021	179	BARATE 99I	ALEP	E^{ee}_{cm}= 161+172+183 GeV
0.102 ±0.009 ±0.002	115	ACCIARRI 98P	L3	E^{ee}_{cm}= 161+172+ 183 GeV
0.10 ±0.01	1216	[53] ABE 92I	CDF	$E^{p\overline{p}}_{\text{cm}}$= 1.8 TeV

• • • We do not use the following data for averages, fits, limits, etc. • • •

$0.1139 \pm 0.0096 \pm 0.0023$	67	ABREU	99K	DLPH	Repl. by ABREU 00K
$0.073\ ^{+0.019}_{-0.017} \pm 0.002$	16	ACKERSTAFF	98D	OPAL	Repl. by ABBIENDI 99D
$0.084\ ^{+0.028}_{-0.024} \pm 0.003$	13	ACCIARRI	97M	L3	Repl. by ACCIARRI 98P
$0.112 \pm 0.02 \pm 0.006$	25	BARATE	97S	ALEP	Repl. by BARATE 99I

[53] ABE 92I quote the inverse quantity as 9.9 ± 1.2 which we have inverted.

$\Gamma(\tau^+\nu)/\Gamma_{\text{total}}$ Γ_4/Γ

VALUE	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
0.1043±0.0041 OUR FIT					
$0.1105 \pm 0.0075 \pm 0.0032$	424	ABREU	00K	DLPH	E^{ee}_{cm}= 161+172+183 +189 GeV
$0.101 \pm 0.010 \pm 0.003$	144	ABBIENDI	99D	OPAL	E^{ee}_{cm}= 161+172+ 183 GeV
$0.0976 \pm 0.0101 \pm 0.0033$	160	BARATE	99I	ALEP	E^{ee}_{cm}= 161+172+ 183 GeV
$0.090 \pm 0.012 \pm 0.003$	81	ACCIARRI	98P	L3	E^{ee}_{cm}= 161+172+ 183 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$0.1095 \pm 0.0149 \pm 0.0041$	47	ABREU	99K	DLPH	Repl. by ABREU 00K
$0.140\ ^{+0.030}_{-0.028} \pm 0.005$	23	ACKERSTAFF	98D	OPAL	Repl. by ABBIENDI 99D
$0.109\ ^{+0.042}_{-0.039} \pm 0.005$	15	ACCIARRI	97M	L3	Repl. by ACCIARRI 98P
$0.113 \pm 0.027 \pm 0.006$	37	BARATE	97S	ALEP	Repl. by BARATE 99I

$\Gamma(\text{hadrons})/\Gamma_{\text{total}}$ Γ_5/Γ

VALUE	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
0.6848±0.0059 OUR FIT					
$0.6789 \pm 0.0073 \pm 0.0043$	1773	ABREU	00K	DLPH	E^{ee}_{cm}= 161+172+183 +189 GeV
$0.679 \pm 0.012 \pm 0.005$	395	ABBIENDI	99D	OPAL	E^{ee}_{cm}= 161+172+ 183 GeV
$0.6893 \pm 0.0121 \pm 0.0051$	1255	BARATE	99I	ALEP	E^{ee}_{cm}= 161+172+ 183 GeV
$0.701 \pm 0.013 \pm 0.004$	462	ACCIARRI	98P	L3	E^{ee}_{cm}= 161+172+ 183 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$0.6746 \pm 0.0143 \pm 0.0052$	465	ABREU	99K	DLPH	Repl. by ABREU 00K
$0.698\ ^{+0.030}_{-0.032} \pm 0.007$	52	ACKERSTAFF	98D	OPAL	Repl. by ABBIENDI 99D
$0.642\ ^{+0.037}_{-0.038} \pm 0.005$	70	ACCIARRI	97M	L3	Repl. by ACCIARRI 98P
$0.677 \pm 0.031 \pm 0.007$	65	BARATE	97S	ALEP	Repl. by BARATE 99I

$\Gamma(\mu^+\nu)/\Gamma(e^+\nu)$ — Γ_3/Γ_2

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.984±0.032 OUR FIT					
0.89 ±0.10	13k	[54] ABACHI	95D	D0	$E_{cm}^{p\overline{p}}$= 1.8 TeV
1.02 ±0.08	1216	[55] ABE	92I	CDF	$E_{cm}^{p\overline{p}}$= 1.8 TeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
1.00 ±0.14 ±0.08	67	ALBAJAR	89	UA1	$E_{cm}^{p\overline{p}}$= 546,630 GeV
1.24 $^{+0.6}_{-0.4}$	14	ARNISON	84D	UA1	Repl. by ALBAJAR 89

[54] ABACHI 95D obtain this result from the measured σ_WB($W \rightarrow \mu\nu$)= 2.09 ± 0.23 ± 0.11 nb and σ_WB($W \rightarrow e\nu$)= 2.36 ± 0.07 ± 0.13 nb in which the first error is the combined statistical and systematic uncertainty, the second reflects the uncertainty in the luminosity.

[55] ABE 92I obtain σ_WB($W \rightarrow \mu\nu$)= 2.21 ± 0.07 ± 0.21 and combine with ABE 91C σ_W B(($W \rightarrow e\nu$)) to give a ratio of the couplings from which we derive this measurement.

$\Gamma(\tau^+\nu)/\Gamma(e^+\nu)$ — Γ_4/Γ_2

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.979±0.044 OUR FIT					
0.94 ±0.14	179	[56] ABE	92E	CDF	$E_{cm}^{p\overline{p}}$= 1.8 TeV
1.04 ±0.08 ±0.08	754	[57] ALITTI	92F	UA2	$E_{cm}^{p\overline{p}}$= 630 GeV
1.02 ±0.20 ±0.12	32	ALBAJAR	89	UA1	$E_{cm}^{p\overline{p}}$= 546,630 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.995±0.112±0.083	198	ALITTI	91C	UA2	Repl. by ALITTI 92F
1.02 ±0.20 ±0.10	32	ALBAJAR	87	UA1	Repl. by ALBAJAR 89

[56] ABE 92E use two procedures for selecting $W \rightarrow \tau\nu_\tau$ events. The missing E_T trigger leads to 132 ± 14 ± 8 events and the τ trigger to 47 ± 9 ± 4 events. Proper statistical and systematic correlations are taken into account to arrive at σB($W \rightarrow \tau\nu$) = 2.05 ± 0.27 nb. Combined with ABE 91C result on σB($W \rightarrow e\nu$), ABE 92E quote a ratio of the couplings from which we derive this measurement.

[57] This measurement is derived by us from the ratio of the couplings of ALITTI 92F.

$\Gamma(\pi^+\gamma)/\Gamma(e^+\nu)$ — Γ_6/Γ_2

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
< 7 $\times 10^{-4}$ (CL = 95%)					
< 7 $\times 10^{-4}$	95	ABE	98H	CDF	$E_{cm}^{p\overline{p}}$= 1.8 TeV
< 4.9 $\times 10^{-3}$	95	[58] ALITTI	92D	UA2	$E_{cm}^{p\overline{p}}$= 630 GeV
<58 $\times 10^{-3}$	95	[59] ALBAJAR	90	UA1	$E_{cm}^{p\overline{p}}$= 546, 630 GeV

[58] ALITTI 92D limit is 3.8×10^{-3} at 90%CL.

[59] ALBAJAR 90 obtain < 0.048 at 90%CL.

$\Gamma(D_s^+\gamma)/\Gamma(e^+\nu)$ — Γ_7/Γ_2

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<1.2 $\times 10^{-2}$	95	ABE	98P	CDF	$E_{cm}^{p\overline{p}}$= 1.8 TeV

$\Gamma(cX)/\Gamma(\text{hadrons})$ Γ_8/Γ_5

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
0.51±0.05±0.03	746	[60] BARATE 99M	ALEP	$E^{ee}_{\rm cm}$= 172 + 183 GeV

[60] BARATE 99M tag c jets using a neural network algorithm. From this measurement $|V_{cs}|$ is determined to be 1.00 ± 0.11 ± 0.07.

$R_{cs} = \Gamma(c\overline{s})/\Gamma(\text{hadrons})$ Γ_9/Γ_5

VALUE	DOCUMENT ID	TECN	COMMENT
$\mathbf{0.46^{+0.18}_{-0.14}\pm0.07}$	[61] ABREU 98N	DLPH	$E^{ee}_{\rm cm}$= 161+172 GeV

[61] ABREU 98N tag c and s jets by identifying a charged kaon as the highest momentum particle in a hadronic jet. They also use a lifetime tag to independently identify a c jet, based on the impact parameter distribution of charged particles in a jet. From this measurement $|V_{cs}|$ is determined to be $0.94^{+0.32}_{-0.26} \pm 0.13$.

AVERAGE PARTICLE MULTIPLICITIES IN HADRONIC W DECAY

Summed over particle and antiparticle, when appropriate.

$\langle N_{charged}\rangle$

VALUE	DOCUMENT ID	TECN	COMMENT
19.3 ±0.4 OUR AVERAGE			
19.3 ±0.3 ±0.3	[62] ABBIENDI 99N	OPAL	$E^{ee}_{\rm cm}$= 183 GeV
19.23±0.74	[63] ABREU 98C	DLPH	$E^{ee}_{\rm cm}$= 172 GeV

[62] ABBIENDI 99N use the final states $W^+W^- \rightarrow q\overline{q}\ell\overline{\nu}_\ell$ to derive this value.

[63] ABREU 98C combine results from both the fully hadronic as well semileptonic WW final states after demonstrating that the W decay charged multiplicity is independent of the topology within errors.

TRIPLE GAUGE COUPLINGS (TGC'S)

Revised March 2000 by C. Caso (Univ. of Genova) and A. Gurtu (Tata Inst.)

Fourteen independent couplings, 7 each for ZWW and γWW, completely describe the VWW vertices within the most general framework of the electroweak Standard Model (SM) consistent with Lorentz invariance and $U(1)$ gauge invariance. Of each of the 7 TGC's, 3 conserve C and P individually, 3 violate CP, and one TGC violates C and P individually while conserving CP. Assumption of C and P conservation and electromagnetic gauge invariance reduces the independent VWW couplings to five: one common set is $(\kappa_\gamma, \kappa_Z, \lambda_\gamma, \lambda_Z, g_1^Z)$, where $\kappa_\gamma = \kappa_Z = g_1^Z = 1$ and $\lambda_\gamma = \lambda_Z = 0$ in the Standard

Model at the tree level. The W magnetic dipole moment, μ_W, and the W electric quadrupole moment, q_W, are expressed as $\mu_W = e\ (1 + \kappa_\gamma + \lambda_\gamma)/2M_W$ and $q_W = -e\ (\kappa_\gamma - \lambda_\gamma)/M_W^2$.

Precision measurements of suitable observables at LEP1 has already led to an exploration of much of the TGC parameter space. Three linear combinations of the TGC's, $\alpha_{W\phi}$, $\alpha_{B\phi}$ and α_W, have been proposed to investigate the leftover "blind" directions in the CP-conserving TGC parameter space, and two linear couplings, $\widetilde{\alpha}_{BW}$ and $\widetilde{\alpha}_W$ in the CP-violating TGC parameter space (see *e.g.*, papers by Hagiwara [1], Bilenky [2], and Gounaris [3,4]). The relations between these parameters and those contained in the above set, expressed as *deviations* from the SM, are $\Delta g_1^Z = \alpha_{W\phi}/c_w^2$, $\Delta\kappa_\gamma = \alpha_{W\phi} +\ \alpha_{B\phi}$, $\Delta\kappa_Z = \alpha_{W\phi} -\ t_w^2\alpha_{B\phi}$ and $\lambda_\gamma = \lambda_Z = \alpha_W$, where c_w and t_w are the cosine and tangent of the electroweak mixing angle. Similarly, $\widetilde{\kappa}_\gamma = \widetilde{\alpha}_{BW}, \widetilde{\kappa}_Z = t_w^2\widetilde{\alpha}_{BW}$ and $\widetilde{\lambda}_\gamma = \widetilde{\lambda}_Z = \widetilde{\alpha}_W$ within the CP-violating sector. The LEP Collaborations have recently agreed to express their results directly in terms of the parameters Δg_1^Z, $\Delta\kappa_\gamma$ and λ_γ.

At LEP2 the VWW coupling arises in W-pair production via s-channel exchange or in single W production via the radiation of a virtual photon off the incident e^+ or e^-. At the TEVATRON hard photon bremstrahlung off a produced W or Z signals the presence of a triple gauge vertex. In order to extract the value of one TGC the others are generally kept fixed to their SM values.

References

1. K. Hagiwara *et al.*, Nucl. Phys. **B282**, 253 (1987).
2. M. Bilenky *et al.*, Nucl. Phys. **B409**, 22 (1993).
3. G. Gounaris *et al.*, CERN 96-01 525.
4. G. Gounaris *et al.*, Eur. Phys. J. **C2**, 365 (1998).

Δg_1^Z

VALUE		EVTS	DOCUMENT ID		TECN	COMMENT
$0.01^{+0.09}_{-0.08}$	**OUR AVERAGE**					
$0.01^{+0.13}_{-0.12}$		853	[64] ABBIENDI	99D	OPAL	E^{ee}_{cm}= 161+172+ 183 GeV
$-0.04^{+0.14}_{-0.12}$		566	[65] ABREU	99L	DLPH	E^{ee}_{cm}= 183 GeV
$0.11^{+0.19}_{-0.18}$	±0.10	1154	[66] ACCIARRI	99Q	L3	E^{ee}_{cm}= 161+172+ 183 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •						
		331	[67] ABBOTT	99I	D0	$E^{p\overline{p}}_{cm}$= 1.8 TeV
$-0.017\pm0.018^{+0.018}_{-0.003}$			[68] MOLNAR	99	THEO	LEP1, SLAC+Tevatron

[64] ABBIENDI 99D combine results from W^+W^- production at different energies. The 95% confidence interval is $-0.23 < \Delta g_1^Z < 0.26$.

[65] ABREU 99L use W^+W^-, $We\nu_e$, and $\nu\overline{\nu}\gamma$ final states. The 95% confidence interval is $-0.28 < \Delta g_1^Z < 0.24$.

[66] ACCIARRI 99Q study W-pair, single-W, and single photon events.

[67] ABBOTT 99I perform a simultaneous fit to the $W\gamma$, $WW \rightarrow$ dilepton, $WW/WZ \rightarrow e\nu jj$, $WW/WZ \rightarrow \mu\nu jj$, and $WZ \rightarrow$ trilepton data samples. For $\Lambda = 2.0$ TeV, the 95%CL limits are $-0.37 < \Delta g_1^Z < 0.57$, fixing $\lambda_Z=\Delta\kappa_Z=0$ and assuming Standard Model values for the $WW\gamma$ couplings.

[68] MOLNAR 99 extract this value indirectly by fitting high energy electroweak data within the framework of the Standard Model. The central value of the Higgs mass used is 300 GeV and the quoted systematic error is due to its variation between 90 to 1000 GeV.

$\Delta\kappa_\gamma$

VALUE		EVTS	DOCUMENT ID		TECN	COMMENT
0.08 ± 0.17	**OUR AVERAGE**					
$0.11^{+0.52}_{-0.37}$		853	[69] ABBIENDI	99D	OPAL	E^{ee}_{cm}= 161+172+ 183 GeV
-0.08 ± 0.34		331	[70] ABBOTT	99I	D0	$E^{p\overline{p}}_{cm}$= 1.8 TeV
$0.19^{+0.32}_{-0.34}$		566	[71] ABREU	99L	DLPH	E^{ee}_{cm}= 183 GeV
0.11 ± 0.25	±0.17	1154	[72] ACCIARRI	99Q	L3	E^{ee}_{cm}= 161+172+ 183 GeV
$0.05^{+1.15}_{-1.10}$	±0.25	207	[73] BARATE,R	98	ALEP	E^{ee}_{cm}= 161+172+183 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •						
		15	[74] BARATE	99L	ALEP	E^{ee}_{cm}= 161+172+183 GeV
$0.016\pm0.019^{+0.009}_{-0.013}$			[75] MOLNAR	99	THEO	LEP1, SLAC+Tevatron
$0.06^{+0.27}_{-0.26}$		86	[76] ACCIARRI	98N	L3	Repl. by ACCIARRI 99Q

[69] ABBIENDI 99D combine results from W^+W^- production at different energies. The 95% confidence interval is $-0.55 < \Delta\kappa_\gamma < 1.28$.

[70] ABBOTT 99I perform a simultaneous fit to the $W\gamma$, $WW \rightarrow$ dilepton, $WW/WZ \rightarrow e\nu jj$, $WW/WZ \rightarrow \mu\nu jj$, and $WZ \rightarrow$ trilepton data samples. For $\Lambda = 2.0$ TeV, the 95%CL limits are $-0.25 < \Delta\kappa_\gamma < 0.39$.

[71] ABREU 99L use W^+W^-, $We\nu_e$, and $\nu\overline{\nu}\gamma$ final states. The 95% confidence interval is $-0.46 < \Delta\kappa_\gamma < 0.84$.

[72] ACCIARRI 99Q study W-pair, single-W, and single photon events.

[73] BARATE,R 98 study single photon production in e^+e^- interactions from 161 to 183 GeV. A likelihood fit is performed to the cross section and to the photon energy and angular distributions, taking into account systematic uncertainties. The 95%CL limits are $-2.2 < \Delta\kappa_\gamma < 2.3$.

[74] BARATE 99L study single W production in e^+e^- interactions from 161 to 183 GeV. They obtain 95%CL limits of $-1.6 < \kappa_\gamma < 1.5$, which we convert to $-2.6 < \Delta\kappa_\gamma < 0.5$ for λ_γ=0.

[75] MOLNAR 99 extract this value indirectly by fitting high energy electroweak data within the framework of the Standard Model. The central value of the Higgs mass used is 300 GeV and the quoted systematic error is due to its variation between 90 to 1000 GeV.

[76] ACCIARRI 98N study single W production in e^+e^- interactions from 130 to 183 GeV. The 95%CL limits are $-0.46 < \Delta\kappa_\gamma < 0.57$.

λ_γ

VALUE	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
$\mathbf{-0.04^{+0.07}_{-0.06}}$ **OUR AVERAGE**					
$-0.10^{+0.13}_{-0.12}$	853	[77] ABBIENDI	99D	OPAL	E^{ee}_{cm}= 161+172+ 183 GeV
$0.00^{+0.10}_{-0.09}$	331	[78] ABBOTT	99I	D0	$E^{p\overline{p}}_{cm}$= 1.8 TeV
$-0.15^{+0.19}_{-0.15}$	566	[79] ABREU	99L	DLPH	E^{ee}_{cm}= 183 GeV
$0.10^{+0.22}_{-0.20}\pm0.10$	1154	[80] ACCIARRI	99Q	L3	E^{ee}_{cm}= 161+172+ 183 GeV
$-0.05^{+1.55}_{-1.45}\pm0.30$	207	[81] BARATE,R	98	ALEP	E^{ee}_{cm}= 161+172+183 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
	15	[82] BARATE	99L	ALEP	E^{ee}_{cm}= 161+172+183 GeV
$-0.48^{+0.44}_{-0.21}$	86	[83] ACCIARRI	98N	L3	Repl. by ACCIARRI 99Q

[77] ABBIENDI 99D combine results from W^+W^- production at different energies. The 95% confidence interval is $-0.33 < \lambda_\gamma < 0.16$.

[78] ABBOTT 99I perform a simultaneous fit to the $W\gamma$, $WW \rightarrow$ dilepton, $WW/WZ \rightarrow e\nu jj$, $WW/WZ \rightarrow \mu\nu jj$, and $WZ \rightarrow$ trilepton data samples. For Λ = 2.0 TeV, the 95%CL limits are $-0.18 < \lambda_\gamma < 0.19$.

[79] ABREU 99L use W^+W^-, $We\nu_e$, and $\nu\overline{\nu}\gamma$ final states. The 95% confidence interval is $-0.44 < \lambda_\gamma < 0.24$.

[80] ACCIARRI 99Q study W-pair, single-W, and single photon events.

[81] BARATE,R 98 study single photon production in e^+e^- interactions from 161 to 183 GeV. A likelihood fit is performed to the cross section and to the photon energy and angular distributions, taking into account systematic uncertainties. The 95%CL limits are $-3.1 < \lambda_\gamma < 3.2$.

[82] BARATE 99L study single W production in e^+e^- interactions from 161 to 183 GeV. The 95%CL limits are $-1.6 < \lambda_\gamma < 1.6$ for $\Delta\kappa_\gamma$=0.

[83] ACCIARRI 98N study single W production in e^+e^- interactions from 130 to 183 GeV. The 95%CL limits are $-0.86 < \lambda_\gamma < 0.75$.

Δg_5^Z

This coupling is CP conserving but C and P violating.

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
$\mathbf{-0.44^{+0.23}_{-0.22}\pm0.12}$	1154	[84] ACCIARRI 99Q	L3	E^{ee}_{cm}= 161+172+ 183 GeV

[84] ACCIARRI 99Q study W-pair, single-W, and single photon events.

$\alpha_{W\phi}$

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
0.05±0.20 OUR AVERAGE				
$0.22^{+0.25}_{-0.28}\pm0.06$	89	[85] ABREU 98K	DLPH	E^{ee}_{cm}=161+172 GeV
$-0.14^{+0.27}_{-0.25}{}^{+0.14}_{-0.12}$	78	[86] BARATE 98Y	ALEP	E^{ee}_{cm}= 172 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •				
	331	[87] ABBOTT 99I	D0	$E^{p\overline{p}}_{cm}$= 1.8 TeV

[85] ABREU 98K obtain this result using both W pair production and single W ($We\nu_e$) production.

[86] BARATE 98Y obtain this value using semileptonic and hadronic decay modes in W pair production.

[87] ABBOTT 99I perform a simultaneous fit to the $W\gamma$, $WW \to$ dilepton, $WW/WZ \to e\nu jj$, $WW/WZ \to \mu\nu jj$, and $WZ \to$ trilepton data samples. For Λ = 2.0 TeV, the 95%CL limits are $-0.18 < \alpha_{W\phi} < 0.36$, fixing $\alpha_{B\phi}$=α_W=0.

α_W

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
0.1 ±0.4 OUR AVERAGE				
$0.11^{+0.48}_{-0.49}\pm0.09$	89	[88] ABREU 98K	DLPH	E^{ee}_{cm}=161+172 GeV
$0.06^{+0.56}_{-0.50}{}^{+0.12}_{-0.20}$	78	[89] BARATE 98Y	ALEP	E^{ee}_{cm}= 172 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •				
	331	[90] ABBOTT 99I	D0	$E^{p\overline{p}}_{cm}$= 1.8 TeV

[88] ABREU 98K obtain this result using both W pair production and single W ($We\nu_e$) production.

[89] BARATE 98Y obtain this value using semileptonic and hadronic decay modes in W pair production.

[90] ABBOTT 99I perform a simultaneous fit to the $W\gamma$, $WW \to$ dilepton, $WW/WZ \to e\nu jj$, $WW/WZ \to \mu\nu jj$, and $WZ \to$ trilepton data samples. For Λ = 2.0 TeV, the 95%CL limits are $-0.18 < \alpha_W < 0.19$, fixing $\alpha_{B\phi}$=$\alpha_{W\phi}$=0.

$\alpha_{B\phi}$

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
$\mathbf{0.4\ ^{+0.5}_{-0.8}}$ **OUR AVERAGE**				
$0.22^{+0.66}_{-0.83}\pm0.24$	89	[91] ABREU 98K	DLPH	E^{ee}_{cm}=161+172 GeV
$1.01^{+0.71}_{-1.75}\pm0.33$	78	[92] BARATE 98Y	ALEP	E^{ee}_{cm}= 172 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •				
	331	[93] ABBOTT 99I	D0	$E^{p\overline{p}}_{cm}$= 1.8 TeV

[91] ABREU 98K obtain this result using both W pair production and single W ($W e \nu_e$) production.

[92] BARATE 98Y obtain this value using semileptonic and hadronic decay modes in W pair production.

[93] ABBOTT 99I perform a simultaneous fit to the $W\gamma$, $WW \rightarrow$ dilepton, $WW/WZ \rightarrow e\nu jj$, $WW/WZ \rightarrow \mu\nu jj$, and $WZ \rightarrow$ trilepton data samples. For $\Lambda = 2.0$ TeV, the 95%CL limits are $-0.67 < \alpha_{B\phi} < 0.56$, fixing $\alpha_{W\phi}=\alpha_W=0$.

$\widetilde{\alpha}_{BW}$

VALUE	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
$\mathbf{0.11^{+0.71}_{-0.88}\pm0.09}$	89	[94] ABREU	98K	DLPH	E^{ee}_{cm}=161+172 GeV

[94] ABREU 98K obtain this result using both W pair production and single W ($W e \nu_e$) production.

$\widetilde{\alpha}_{W}$

VALUE	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
$\mathbf{0.19^{+0.28}_{-0.41}\pm0.11}$	89	[95] ABREU	98K	DLPH	E^{ee}_{cm}=161+172 GeV

[95] ABREU 98K obtain this result using both W pair production and single W ($W e \nu_e$) production.

W ANOMALOUS MAGNETIC MOMENT ($\Delta\kappa$)

The full magnetic moment is given by $\mu_W = e(1+\kappa+\lambda)/2m_W$. In the Standard Model, at tree level, $\kappa=1$ and $\lambda=0$. Some papers have defined $\Delta\kappa = 1-\kappa$ and assume that $\lambda=0$. Note that the electric quadrupole moment is given by $-e(\kappa-\lambda)/m^2_W$. A description of the parameterization of these moments and additional references can be found in HAGIWARA 87 and BAUR 88. The parameter Λ appearing in the theoretical limits below is a regularization cutoff which roughly corresponds to the energy scale where the structure of the W boson becomes manifest.

VALUE ($e/2m_W$)	*DOCUMENT ID*		*TECN*
• • • We do not use the following data for averages, fits, limits, etc. • • •			
	[96] ABE	95G	CDF
	[97] ALITTI	92C	UA2
	[98] SAMUEL	92	THEO
	[99] SAMUEL	91	THEO
	[100] GRIFOLS	88	THEO
	[101] GROTCH	87	THEO
	[102] VANDERBIJ	87	THEO
	[103] GRAU	85	THEO
	[104] SUZUKI	85	THEO
	[105] HERZOG	84	THEO

[96] ABE 95G report $-1.3 < \kappa < 3.2$ for λ=0 and $-0.7 < \lambda < 0.7$ for κ=1 in $p\overline{p} \rightarrow e\nu_e\gamma X$ and $\mu\nu_\mu\gamma X$ at $\sqrt{s}$ = 1.8 TeV.

[97] ALITTI 92C measure $\kappa = 1^{+2.6}_{-2.2}$ and $\lambda = 0^{+1.7}_{-1.8}$ in $p\overline{p} \rightarrow e\nu\gamma + X$ at $\sqrt{s}$ = 630 GeV. At 95%CL they report $-3.5 < \kappa < 5.9$ and $-3.6 < \lambda < 3.5$.

[98] SAMUEL 92 use preliminary CDF and UA2 data and find $-2.4 < \kappa < 3.7$ at 96%CL and $-3.1 < \kappa < 4.2$ at 95%CL respectively. They use data for $W\gamma$ production and radiative W decay.

[99] SAMUEL 91 use preliminary CDF data for $p\overline{p} \rightarrow W\gamma X$ to obtain $-11.3 \leq \Delta\kappa \leq 10.9$. Note that their $\kappa = 1-\Delta\kappa$.

[100] GRIFOLS 88 uses deviation from ρ parameter to set limit $\Delta\kappa \lesssim 65\ (M_W^2/\Lambda^2)$.

[101] GROTCH 87 finds the limit $-37 < \Delta\kappa < 73.5$ (90% CL) from the experimental limits on $e^+e^- \rightarrow \nu\overline{\nu}\gamma$ assuming three neutrino generations and $-19.5 < \Delta\kappa < 56$ for four generations. Note their $\Delta\kappa$ has the opposite sign as our definition.

[102] VANDERBIJ 87 uses existing limits to the photon structure to obtain $|\Delta\kappa| < 33\ (m_W/\Lambda)$. In addition VANDERBIJ 87 discusses problems with using the ρ parameter of the Standard Model to determine $\Delta\kappa$.

[103] GRAU 85 uses the muon anomaly to derive a coupled limit on the anomalous magnetic dipole and electric quadrupole (λ) moments $1.05 > \Delta\kappa\ \ln(\Lambda/m_W) + \lambda/2 > -2.77$. In the Standard Model $\lambda = 0$.

[104] SUZUKI 85 uses partial-wave unitarity at high energies to obtain $|\Delta\kappa| \lesssim 190\ (m_W/\Lambda)^2$. From the anomalous magnetic moment of the muon, SUZUKI 85 obtains $|\Delta\kappa| \lesssim 2.2/\ln(\Lambda/m_W)$. Finally SUZUKI 85 uses deviations from the ρ parameter and obtains a very qualitative, order-of-magnitude limit $|\Delta\kappa| \lesssim 150\ (m_W/\Lambda)^4$ if $|\Delta\kappa| \ll 1$.

[105] HERZOG 84 consider the contribution of W-boson to muon magnetic moment including anomalous coupling of $WW\gamma$. Obtain a limit $-1 < \Delta\kappa < 3$ for $\Lambda \gtrsim 1$ TeV.

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ABBIENDI	99N	PL B453 153	G. Abbiendi *et al.*	(OPAL Collab.)
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ABE	98P	PR D58 091101	F. Abe *et al.*	(CDF Collab.)
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